Fleet Integration for Multi-Mission Operations Center

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Abstract

The NASA Goddard Space Flight Center (GSFC) Small Explorer (SMEX) mission operations team is currently involved in reengineering the Mission Operations Center (MOC) to infuse new software technologies to support an aging fleet of space science satellites. Four SMEX satellites are currently being commanded and monitored by GSFC, each with its own independent ground system. The objective of the reengineering effort is to demonstrate fleet operations concepts and the potential for mission operations cost reductions for future science constellation missions. This paper will give details of this migration towards a consolidated, fleet oriented MOC.

I. Introduction

The NASA Goddard Space Flight Center (GSFC) Small Explorer (SMEX) mission operations team is currently involved in reengineering the Mission Operations Center (MOC) to infuse new software technologies to support an expanding fleet of aging earth orbiters. Most of the SMEX satellites have entered their extended life phase but are still providing useful science data for the primary investigators. Four SMEX satellites are currently commanded and monitored by GSFC in conjunction with a local Maryland university. Also in conjunction with a California university, an additional two SMEX satellites will be controlled and monitored. The GSFC SMEX MOC originally began with 24 hour by 7 day staffed operations, but has since reduced staffed operations to a single 8 hour shift, 5 days a week.

Since the SMEX missions are extended-life ‘engineering’ missions, they are now being used to demonstrate heterogeneous mission operations performed on a single fleet-oriented mission operations platform. The primary motivator for this path-finding expedition is to demonstrate and exercise fleet control and concepts for future missions while revealing the costs savings that could be realized with this type of consolidated architecture. Secondary motives are to demonstrate several new ground-based technologies with operational missions that are capable of accepting more risk, making it more viable to infuse these technologies into future missions.

II. SMEX Mission Descriptions

The SMEX missions are part of NASA’s long-standing Explorer program designed to provide frequent flight opportunities for inexpensive, well-focused science missions. The cost cap for any SMEX mission is $120 million total cost to NASA, which includes the definition, development, launch services, mission operations, and data analysis aspects of the mission.[1] The SMEX satellites weigh between 180 and 250 kg, and have a typical power consumption of 50 to 200 watts.

Beginning in 1992, with the launch of the first SMEX satellite called SAMPEX, NASA has launched a total of six SMEX satellites to date (see Table 1). Even though the life expectancy of these satellites collectively is under 1.5 years, these missions are still operational in part to the cost-effective operational concepts currently in place. One concept recently implemented is to co-locate mission operations between GSFC and multiple universities (see Table 2). Although GSFC primarily handles operations for only two missions, the Goddard SMEX MOC has been

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configured to support backup operations for the two missions flown out of Bowie State University. GSFC is also currently working with the University of California, Berkeley to provide backup operations for the remaining two SMEX missions.

Table 1 Current SMEX missions and their lifetime expectancies[2]

Satellite	Launch Date	Expected lifetime	Mass	Orbit	Operations
SAMPEX	July 3, 1992	3 years	157 kg	550 km x 675 km, 82°	Two passes per day, 12 hours apart
FAST	August 21, 1996	1 year	191 kg	351 km x 4175 km, 83°	One pass per orbit (10-12 passes daily)
TRACE	April 1, 1998	1 year	250 kg	600 km x 650 km, 97.80°	Four – six passes per day
SWAS	December 5, 1998	2 years	288 kg	637 km x 653 km, 69.90°	Two passes per day, 12 hours apart
WIRE	March 3, 1999	4 months	258.7 kg	540 km x 590 km, 97.56°	Two passes per day, 12 hours apart
RHESSI	May 5, 2002	3 years	304 kg	587 km x 600 km, 38°	Six – nine passes per day (95 minute orbit)

Table 2 Primary SMEX operations centers

Mission	Operations Center
SAMPEX	Bowie State University
FAST	University of California, Berkeley
SWAS	Goddard Space Flight Center
TRACE	Goddard Space Flight Center
WIRE	Bowie State University
RHESSI	University of California, Berkeley

III. Extended Operations

When the missions entered extend operations, the Flight Operations Team (FOT) was challenged to continue support for these missions on a reduced budget. Although located within the same facility, SAMPEX, SWAS, TRACE, and WIRE all have individual software and hardware systems for mission operations at GSFC. Typically as new SMEX missions were implemented in the MOC, each mission was modeled after the previous one with respect to software and operations, creating strong system cohesion between all the missions. There are numerous architectural commonalities between these systems including (see Figure 1):

- the use of the Integrated and Test and Operations System (ITOS) for the telemetry and command system, although each mission has unique telemetry and command databases
- the use of the White Sands Scheduling Group and the Command Management System for scheduling and load generation
- the use of Data Trending and Analysis System (DTAS) for trend analysis
- the use of Virtual MOC (VMOC) for anomaly detection, paging and tracking anomaly resolutions

Since these components are common to all missions, these missions inherently share the same data formats, conventions, and standards. Each mission uses the same combination of ground station supports provided by the NASA Ground Network (Wallops, Virginia; Poker Flat, Alaska; McMurdo Antarctica; and the Merritt Island Launch Annex (MILA), Florida). There are also variations between the mission systems which impacts how ground system architectures can be implemented generically to support all missions. SAMPEX, being the oldest SMEX satellite, has a different on-board architecture than the other missions, which affects the MOC. This forces the MOC for example to deal with a SAMPEX-unique mnemonic naming convention. Another variation is the generation of the flight dynamics ephemeris and products. Currently, there exist three distinct operational concepts for generating the flight dynamics products; two of which involve out-sourcing some level of the generation capabilities to different facilities. In this case however, the commonalities outweigh the variations, making the GSFC SMEX MOC ideal for exploring fleet concepts and as a proving ground for future fleet-based missions.

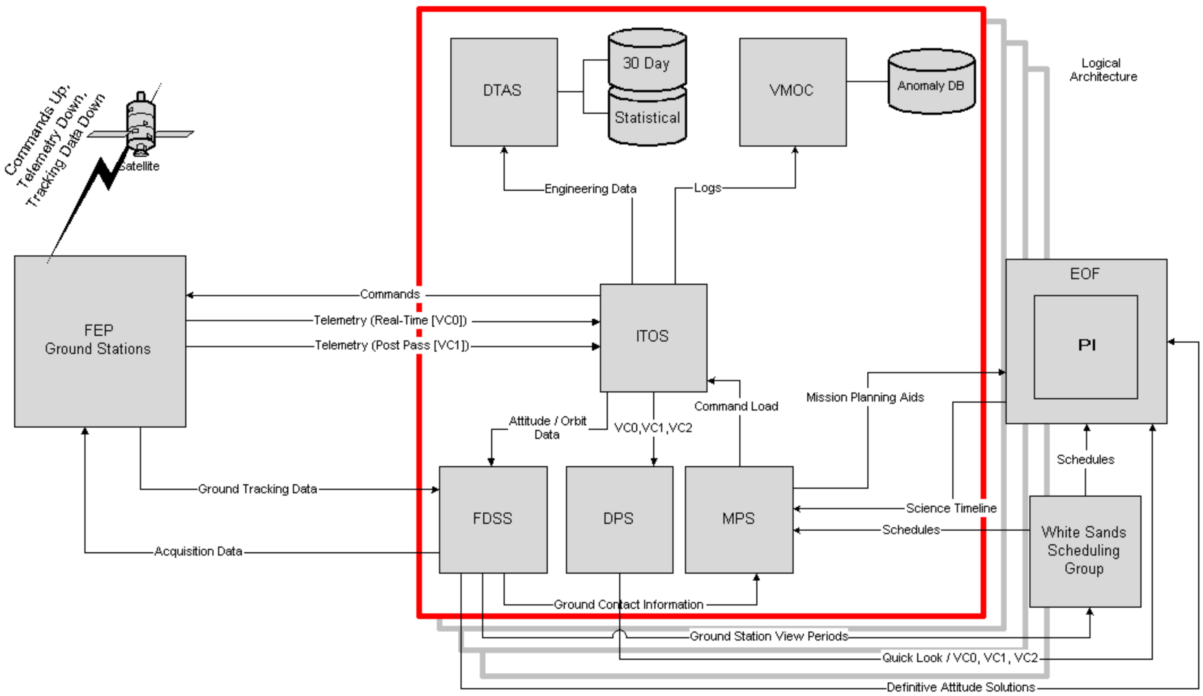

Figure 1 the current system architecture replicates the health and safety system components for each mission.

With respect to operating the satellite, the FOT are either certified as a command controller or a spacecraft analyst. Spacecraft analysts are trained as command controllers, but also have in-depth understanding of the systems onboard the satellite. Both a command controller and a spacecraft analyst typically monitor the staffed ground contacts. Given the infrequency of ground contacts, all operators are cross-trained on the other missions and will monitor multiple missions daily. As previously described, one of the cost-cutting techniques employed by GSFC was to outsource operations for two of the missions to Bowie State University, where student flight operators under the guidance of a spacecraft analyst setup and monitor the passes. Not only are the students gaining experience by working with real missions, but Goddard could potentially gain trained satellite operators for other missions, thereby reducing the cost of hiring and training new personnel. The students are responsible for pass scheduling, load generation, and console operations during a pass. Any anomaly resolution is performed by the engineers at GSFC.

Command controllers are generally staffed in a single 8 hour shift Monday through Friday. A number of automation advancements have been made to eliminate staff during nightshifts and weekends. A typical automated pass may be conducted as follows:

1. The spacecraft on-board software automatically begins the data dump at the schedule time, thereby eliminating the need for a dump command to be sent from the ground.
2. The ground station automatically receives this dump data and will forward the real-time and post-pass data to the MOC.
3. The MOC telemetry and command system will transmit a no-operation command to reset the spacecraft hardware timers and begin the housekeeping data processing. For the real-time data, the T&C system will limit check the data and dispatch the appropriate alerts.
4. The Virtual Mission Operations Center (VMOC) system processes the post-pass data once the pass is complete and also performs a limit-check. The FOT are paged for anomalies detected based on the VMOC rule configuration. VMOC will then publish the anomaly and additional information to a web-site where the FOT can log-in to retrieve the satellites vitals.

The current level of automation was achieved through procedural changes and software technologies. First, a procedural change was necessary in order to give the satellite the necessary tracking data to cover the unmanned periods. Vector data is propagated on-ground and uploaded three days a week to cover 72-hour unmanned periods. Second, a number of software procedures were introduced via Systems Test and Operations Language (STOL) scripts into ITOS to detect the start of a pass and to post-process data. Third, multiple UNIX scripts were developed to distribute the post-processed data to the recipients, where more scripts are invoked that trigger additional data processing. Finally, the systems involved had to be modified and/or configured to automatically detect the presence of data. The current system does not have any level of system interoperability besides being able to detect a file change or if a new file has been delivered.

IV. GMSEC Fleet Integration

The GSFC Mission Services Evolution Center (GMSEC) Project was founded in 2001 to support and infuse modern information technologies into both existing and future mission operations. As a result of this effort, the GMSEC architecture was developed and released to support greater component interoperability. The GMSEC architecture uses commercial Message Oriented Middleware (MOM) and a common messaging standard to provide interoperability of MOC systems and offer missions choices during the component selection process and throughout the mission lifecycle[3]. With this architecture, GMSEC compliant components can be quickly selected and integrated into the MOC and configured to interoperate. The GMSEC architecture also allows missions to defer their component selection, since the integration and interfaces are already defined. GMSEC also provides the missions with an evolution path to cope with hardware and software obsolescence. Components can quickly be configured to run in parallel, allowing verification and testing of the new system before switching full operations to that system. This is an important characteristic when dealing with missions which have exceeded their life expectancy by over a decade.

The use of MOM hides the protocol and connection properties required in traditional point-to-point communications and provides advanced services, such as guaranteed message delivery, server load-balancing and fail-over, and communications encryption. To avoid not being coupled with one middleware vendor, GMSEC developed an abstraction layer to provide applications a consistent interface while hiding vendor specific middleware implementations. GMSEC does not provide a middleware solution, so an external middleware software package must be utilized. While other products have and will be used, Tibco SmartSockets was chosen as the primary middleware backbone for this integration effort, due to its demonstrated capabilities for handling multiple, high-volume data streams and its central server architecture. GMSEC also provides guidance on standard GMSEC message formats for numerous messages, including log, heartbeat, telemetry, and product messages. GMSEC itself is not a standards organization, but incorporates current standards such as CCSDS frame and packet standards. The GMSEC message content largely focuses on the routing, broadcasting of information in support of compliant components. This layered approach (see Figure 2) provides missions with a great deal of flexibility in their component and environment selections.

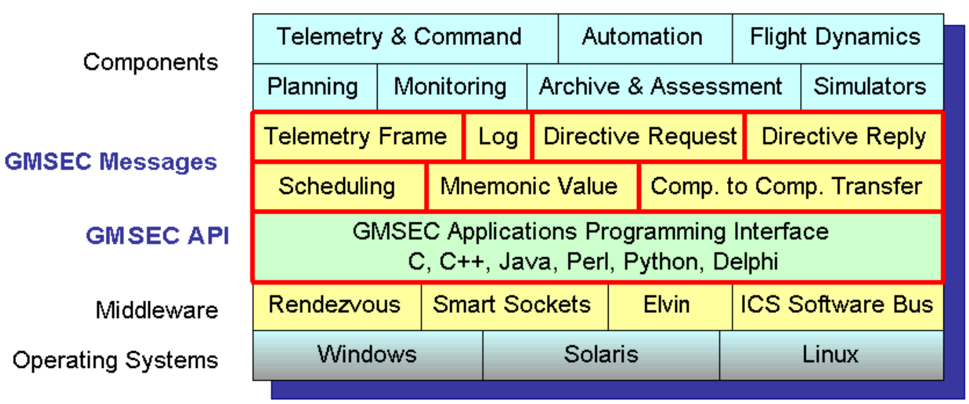

Figure 2 the GMSEC architecture provides a standard messaging scheme as well as interface to become middleware vender independent.

Vendor adoption of the GMSEC standards is vital to providing missions with GMSEC compliant components for integration. GMSEC is currently supporting these vendors as well as funding internal development efforts. The commanding and telemetry monitoring role for SMEX is being fulfilled by L3 Storm's InControl-NG (ICNG) multisatellite telemetry and command tool. ICNG has a client-server configuration which provides support for multiple missions simultaneously from a single system, while providing the FOT with multiple interfaces to access and control any of the missions from within the MOC. A fleet view provides the operators with an over-all health display while alpha-numeric displays provide the FOT with satellite specific mnemonic monitoring.

The first step in T&C integration was porting the existing ITOS command and telemetry databases to the ICNG format and configuring ICNG with the station contact information. Additionally, the ITOS alpha-numeric displays were ported to the ICNG format. This level of integration provides SMEX with a socket interface to the ground stations for transmitting telemetry. As part of this Phase 1 wrap-up, ICNG was demonstrated with 4 simultaneous telemetry streams using looping, past-pass telemetry sets, since SMEX will rarely have 2 passes occur simultaneously. To utilize the GMSEC telemetry message, ITOS was customized to take an in-bound telemetry socket connection and generate GMSEC telemetry messages which are published to the middleware. Once on the middleware bus, ICNG can subscribe to the data and process the raw telemetry frames. It is conceivable that in the future, the ground stations will be publishing telemetry directly to the middleware, as opposed to using a socket connection.

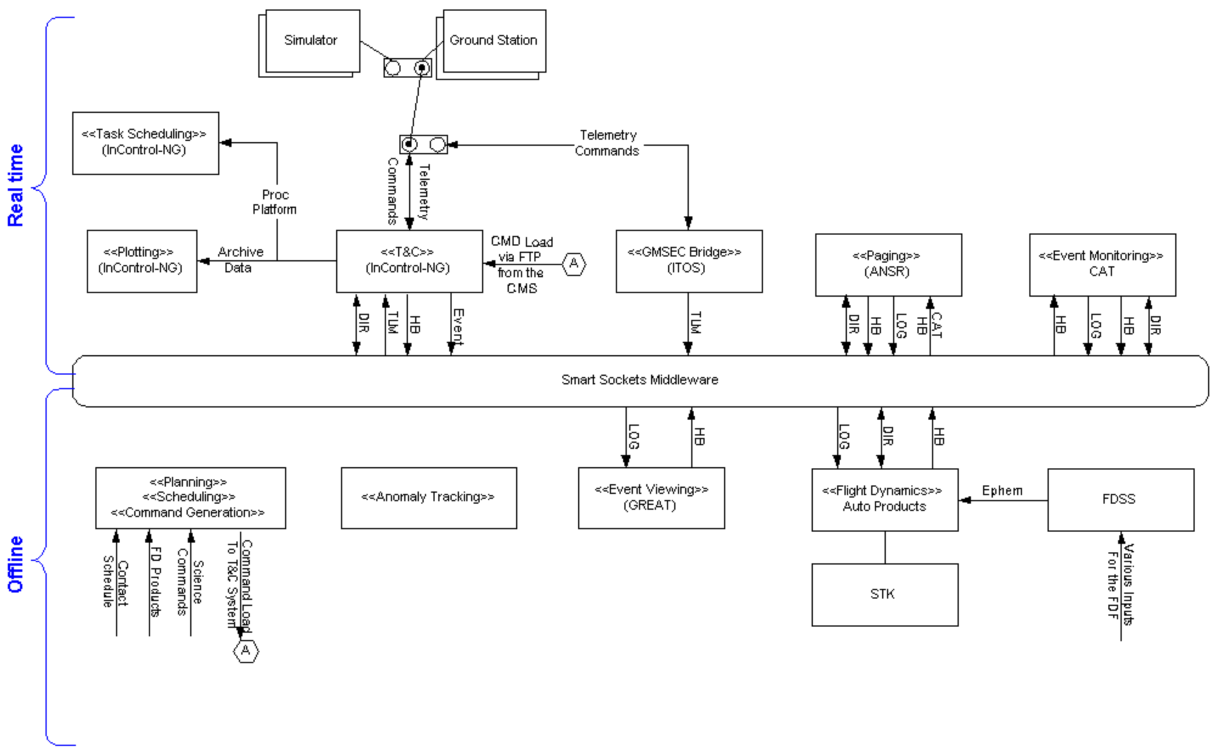

Figure 3 Under the GMSEC architecture, each SMEX MOC component will support the fleet and collaborate through a commercial middleware and standardized interfaces.

V. Automation Approach

To support the reduced budgets of extended life missions, SMEX has adopted a constructive attitude towards the use of automation in supporting these missions. The FOT staffs a single shift during weekdays, with the automation responsible for two shifts per day and weekends. The primary focus for automation traditionally has been real-time health and safety monitoring of the satellites, with a secondary emphasis on the offline automation.

A. Satellite health and safety automation

During unmanned passes the FOT relies on multiple levels of automation to monitor spacecraft safety. The ICNG integrated scheduler will be used to provide both time and event driven automation of the passes. The pass schedules generated by the external scheduling group are translated into a format suitable for ingest by the ICNG scheduler. ICNG will then invoke a pre-pass procedure approximately 40 minutes prior to signal acquisition to verify the ground network connection and prepare to accept the pass. Again, the downlink of telemetry is already automated, so once the telemetry is flowing during lights-out operations, the only command sent is to reset the on-board timers. Real-time decommutation and limit checking is performed by the T&C system, which publishes alert messages via the middleware for violations of analog or discrete information. During staffed periods, these violations are rendered on the console displays. But during unmanned periods, a rule-based engine subscribes for these alerts and warnings, and takes appropriate actions based on predefined system rules. Typically these rules result in a page directive being sent to the VMOC paging system via the middleware, triggering the paging system to notify the FOT and send any available data along with the page. In the event the automation fails, the upcoming pass is aborted and the FOT is notified. While the automation system will automatically retry for the next pass, no dynamic pass scheduling is performed at this time. The operational issues of having multiple missions controlled by the scheduler and the need for ad-hoc schedule modifications are under investigation.

Throughout the pass, a real-time event analysis tool examines each event message to match criteria within its rule database. Event messages could be generated by the satellite itself, the ground station, or the T&C system. Typically the event analysis searches for telemetry values not within acceptable safe ranges, and would send a directive to the paging system for operator notification. The long-term objective is to develop a self-correcting system, but early steps to this approach will include the operators until the level of trust in the automation is raised.

B. Flight Dynamic Product Generation Automation

The greatest variation among these missions is the generation of satellite ephemeris and the orbital and attitude products. At GSFC, two missions perform this entire process in the MOC. Another mission outsourced the generation to the University of Maryland, and yet another outsourced the generation to the GSFC institutional Flight Dynamics Facility (FDF). However, in August 2004, the contract with the University of Maryland for this effort ended, offering an opportunity to integrate the SAMPEX flight dynamics function into the fleet system. With the University contract ending, the SMEX team worked with the FDF team to implement a hybrid variation, where the ephemeris generation and validation is performed at the FDF and all product generations are performed at the MOC.

The products generated by the FOT include orbital vectors and numbers, ground tracks, duration events, and ground station accesses. The original MOC system was configured around the commercially available Satellite Toolkit (STK) and GSFC's own AutoProducts. AutoProducts interfaces with STK to provide automated product generation by invoking STK capabilities. For the fleet system, AutoProducts was modified to support the GMSEC interface and messaging directives, allowing the application to accept processing directives across the middleware to trigger the generation of certain products or all products. Once the products are completed, or an error has been encountered, AutoProducts publishes notification messages to the middleware to alert other subsystems. Work is continuing on the remaining missions to fit within this paradigm of providing a single system for all product generation for all the GSFC SMEX missions.

VI. Conclusion

With the renewed effort for Lunar and Mars exploration there are significant incentives to explore architectures for simplifying and consolidating operations while curbing operational costs. Also, Programs such as sensor webs and virtual apertures, which could contain dozens of small satellites, are in their early conceptual stage and will require new paradigms for their operations. To provide value-added support to GSFC's upcoming missions, the SMEX team is currently working with near-term planned missions on defining operational concepts for fleets and providing a test-bed for new technologies. Automation, whether on-board or on-ground, is believed to be a large part of fleet management. Of interest to SMEX is the on-ground automation of existing satellites to provide extended operations cost-effectively. To this extent, SMEX will be examining further automation issues, such as dynamic station scheduling as an approach to recovering from a blown pass or as a mechanism to avoid schedule conflicts. SMEX will also be defining what is necessary to provide full lights-out operations as part of extending this effort once the system integration has completed.

Endnotes

[1] "NASA GSFC Explorer Web Site" [online database], URL http://explorers.gsfc.nasa.gov/missions.html [cited June 17, 2004]

[2] Watzin, J., "Small Explorer's Web Site" [online database], URL http://sunland.gsfc.nasa.gov/smex/ [cited May 21, 2004]

[3] Cary, E., Smith, D. "A Modular, Data Driven System Architecture for GSFC Ground Systems," *6th Annual Ground System Architecture Workshop,* Manhattan Beach, CA, 2004